

3-D CFD Simulation and Validation of Oxygen-Rich Hydrocarbon Combustion in a Gas-Centered Swirl Coaxial Injector using a Flamelet-Based Approach.

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Injector design is a critical part of the development of a rocket Thrust Chamber Assembly (TCA). Proper detailed injector design can maximize propulsion efficiency while minimizing the potential for failures in the combustion chamber. Traditional design and analysis methods for hydrocarbon-fuel injector elements are based heavily on empirical data and models developed from heritage hardware tests. Using this limited set of data produces challenges when trying to design a new propulsion system where the operating conditions may greatly differ from heritage applications.

Time-accurate, Three-Dimensional (3-D) Computational Fluid Dynamics (CFD) modeling of combustor flows inside of injectors has long been a goal of the fluid analysis group at Marshall Space Flight Center (MSFC) and the larger CFD modeling community. CFD simulation can provide insight into the design and function of an injector that cannot be obtained easily through testing or empirical comparisons to existing hardware. However, the traditional finite-rate chemistry modeling approach utilized to simulate combustor flows for complex fuels, such as Rocket Propellant-2 (RP-2), is prohibitively expensive and time consuming even with a large amount of computational resources. MSFC has been working, in partnership with Streamline Numerics Inc., to develop a computationally efficient, flamelet-based approach for modeling complex combustor flow applications. In this work, a flamelet modeling approach is used to simulate time-accurate, 3-D, combustor flow inside a single Gas Centered Swirl Coaxial (GCSC) injector using the flow solver, Loci-STREAM.

CFD simulations were performed for several different injector geometries. Results of the CFD analysis helped guide the design of the injector from an initial concept to a tested prototype. The results of the CFD analysis are compared to data gathered from several hot-fire, single element injector tests performed in the Air Force Research Lab EC-1 test facility located at Edwards Air Force Base.